SACLANTCEN MEMORANDUM
serial no.: SM-306

SACLANT UNDERSEA RESEARCH CENTRE MEMORANDUM

SUB-SEAFLOOR BURIED REFLECTORS IMAGED BY LOW FREQUENCY ACTIVE SONAR

M.D. Max, N. Portunato, and G. Murdoch

June 1996

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

The SACLANT Undersea Research Centre provides the Supreme Allied Commander Atlantic (SACLANT) with scientific and technical assistance under the terms of its NATO charter, which entered into force on 1 February 1963. Without prejudice to this main task – and under the policy direction of SACLANT – the Centre also renders scientific and technical assistance to the individual NATO nations.

NATO SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

Tel: +39 187 540.111
Fax: +39 187 524.600

e-mail: library@saclantc.nato.int

NORTH ATLANTIC TREATY ORGANIZATION

Sub-seafloor buried reflectors imaged by low frequency active sonar

M. D. Max, N. Portunato & G. Murdoch

The content of this document pertains to work performed under Project 042-3 of the SACLANTCEN Programme of Work. The document has been approved for release by The Director, SACLANTCEN.

David L. Bradley
Director

intentionally blank page

Sub-seafloor buried reflectors imaged by low frequency active sonar

M. D. Max, N. Portunato & G. Murdoch

Executive Summary: Low Frequency Active Sonar (LFAS) false contact rates may be substantially reduced by using GIS(Geographical Information System) technology to properly place seafloor and sub-bottom reverberation sources. A GIS/DMap system (Geographical Information System linked to a relational database containing environmental information of an operational character) has been used to resolve LFAS anomalous targets. Real-time reverberation maps of continental shelf areas have been created as new map layers within the GIS, which already contains bathymetry and acoustic reverberation prediction maps.

As part of two joint SACLANTCEN-NUWC LFAS trials on the northern Malta Plateau sea area, sonar responses apparently from the seafloor were mapped using a GIS linked to the experimental sonar equipment. Investigations using a swath mapper in bathymetric and backscatter modes (side-scan emulation) showed only an acoustically smooth seafloor that would not have been expected to cause the observed sonar responses.

During the course of a subsequent cruise to the area in late January, 1996, these anomalous sonar response areas were investigated using side-scan sonar in conjunction with high-resolution reflection seismics. The anomalous acoustic zones were identified as responses from geological features beneath the 10 to 25 m thick, muddy sediments which form the smooth seafloor. These findings lead to the conclusion that when using TVDS (Towed Vertically Directive Source) at a frequency of 600 Hz, sonar responses can be generated from geological features as small as 3 m high (estimated total area 600 m^2) beneath soft, acoustically low loss muds.

These results demonstrate that reverberation prediction for LFAS systems is a more complex process than previously anticipated. For accurate LF reverberation prediction, an assessment of the recent geoenvironmental history and the upper sub-seafloor strata is necessary. A predictive model for use with the system in other shallow water areas must be based on recent climatological-ocean history which takes into account the nature of the sub-bottom immediately below the recent marine sediment, as well as the seafloor itself.

intentionally blank page

Sub-seafloor buried reflectors imaged by low frequency active sonar

M. D. Max, N. Portunato & G. Murdoch

Abstract: Low Frequency Active Sonar (LFAS) utilizes low-frequency acoustic emissions to detect submarines. Where strong reflections occur on the seabottom which produce environmental scatter (reverberation), response from the submarine target may be masked or false contacts may be reported. Constructing predictive maps of anticipated sonar response zones in order to identify the background clutter is one of the main goals in the preparation of environmental data sets for areas in which LFAS may be employed operationally.

It has been demonstrated that reflectors buried in the seafloor can cause substantial reflections that will be mapped geographically incorrectly where the incident acoustic ray-paths pass back from the buried reflector toward the receiving array through the seafloor. Thus, it is necessary to characterize fully both the seafloor *and* the sub-seafloor acoustic response of shallow water areas in which LFAS ASW operations may be carried out.

Keywords: LFAS – low frequency active sonar – false contacts – bottom properties

Contents

1 Introduction

This Report describes the use of the SACLANTCEN GIS/DMap (computer software consisting of a geographical information system and a wide variety of numerical, image, and text information linked through a relational data base) in support of a Low Frequency Active Sonar (LFAS) sea trial in the northern Malta Plateau between Sicily and Malta. Predictive reverberation maps of likely seafloor reflectors (rock pinnacles, islands, drill rigs, slope scarps, coastal headlands, areas of rough, rocky seafloor, wrecks, etc.) had been compiled in advance of the LFAS exercises and used at sea. These anticipated sonar response zones were included as separate map layers in the SACLANTCEN GIS/DMap of the Sicilian-Tunisian Platform.[1]

During the course of two LFAS trials in the northern Malta Plateau trial area south of SE Sicily the GIS was interfaced with the sonar UNIX workstations where the acoustic echoes were displayed in polar coordinates relative to the ship. The contacts found on the sonar display, on a ping-by-ping basis, were selected by the chief sonar operator. After selection, the contacts were translated into geographical coordinates and communicated using interface software to the GIS. This process allowed sonar response maps to be compiled as new map layers in the GIS.

Where the acoustic responses coincided with the prepared maps of sonar reverberation, the source of the response was identified. The 'mapped' acoustic response areas proved useful in that many of the environmental features could be correlated with them, but a significant number of acoustic response areas could not be correlated with seafloor features. Where no obvious seafloor environmental element or an artifact such as a wreck could be related to observed acoustic responses, these were identified and marked for further investigation.

Individual responses within these zones were usually related to a specific ship position, suggesting that end range, azimuth, and depression combination was unique, such as may be expected from a rough cliff face with a series of reflecting facets at different angles within the cliff. In a number of cases, the response areas were mapped using the shallow water swath (multibeam bathymetric mapper) in both bathymetry and side-scan mode. However none of the surveys made during the exercises showed anything other than the charted smooth seafloor.

During the Winter Sun-2 Cruise in late January, 1996[2], some of these previously identified 'anomalous' LFAS reverberation areas south of Sicily (Fig. 1) were surveyed. It was considered that if an environmental cause could be found for the sites investigated, then development of a methodology for preparing an LFAS environmental prediction chart for shelf areas could be substantially enhanced. Only

[1] Max, M.D. & Spina, F. with Portunato, N. Nardini, P. Turgutcan, F. & Risso, R. Sicilian-Tunisian Platform. SACLANTCEN CD-ROM AREA DMap series DM 5

[2] Max, M.D. (Scientist in charge) Cruise Report, Winter Sun 2

a few of the more prominent anomalous sonar response zones of particular interest were investigated (Fig. 2).

2
A brief geological tutorial and discussion of the northwest Sicily-Malta Plateau

Although it was anticipated that the high power/low frequency LFAS source would result in significant seafloor penetration, no experiments had been carried out previously to evaluate this phenomenon. As superficial examination of the seafloor had found nothing to explain the responses, it appeared likely that if the mapped acoustic responses were not system artifacts or the product of unresolved port-starboard ambiguity, the responses were indeed generated in the immediate sub-bottom. The reflecting facets from a rough rockhead, masked by a thin layer of recent marine sediments, have the potential to generate sonar responses. Their apparent position (Fig. 3) on the seafloor may be different from the actual position.

Almost all continental shelves have seafloors which differ from deeper water seafloors in a number of ways [1]. The most fundamental of these differences is that while deeper water areas have continuous sections of thick marine sediments, there is often little or no marine sediment on continental shelves due to falling water level, and exposure to subareal (atmospheric) conditions.

Sea levels are constantly either rising or falling slowly as part of the earth's climatological cycle. These changes are related to glacial advances and retreats, particularly over the last million years, the Pleistocene era [2]. At the close of the most recent glacial episode, the Weischellian, about 10,000 years ago, sea levels on the Sicilian-Tunisian Platform appear to have been about 130m lower than at present [3]. Subsequently, there was a relatively rapid sea level rise between 10.000 and 6.000 years ago, rising more slowly to near current levels about 5000 years ago [4]. Sea levels are still rising slowly at about 4 mm/year.

This glacial cycle has determined the areas of continental shelves which were periodically submerged and subject to marine sediment when the glaciers retreated. Shelves subjected to marine sediment deposition were exposed to subareal conditions when sea level fell due to the onset of glaciation and ocean cooling. At each rise in sea level, new marine sediments were deposited. Each sea level reduction, exposed sediment which was compacted and lithified due to chemical changes caused by flowing fresh water replacing stagnant sea water.

In addition to mass and physical property changes, the marine sediments, which commonly formed flat or gently sloping seafloors without appreciable lateral variations, were subject to erosion. The upper surface develops a rougher morphology because of the development of river channel systems. These are often cut deeply into the recently exposed sediment. Beach terraces, gravel berms, wave-cut cliff-faces, and features associated with temporary pauses in sea level rise, all can form as erosional relics on the exposed surface.

Although the present seafloor of the West Malta Plateau Terrane is flat and almost everywhere covered with a veneer of muddy marine sediment, it was relatively recently

an eroding coastal alluvial plain, similar to modern subareal alluvial plains, such as the lower Magra Valley (Italy) and the flat coastal area centred on Pisa (Italy). The erosional features that can be anticipated below the recent marine sediments are essentially the same as those which can presently be seen in modern exposed topography. For example, where the land is flattest and the coastal plain is widest, rivers such as the Arno are broadest. In other coastal areas there may also be complexly interwoven meandering channels. Where the coastal plains approach foothills, streams tend to flow more directly toward the sea down local slopes and therefore become more deeply incised. At the base of the hills, wave-cut cliffs may form.

The search for environmental causes for the 'anomalous' reverberation was carried out using a hypothesis of buried geological targets. A high resolution reflection seismic system was used as reflecting facets as small as 1 m (vertical) had to be imaged. A side-scan sonar produced a high resolution swath to either side of the reflection seismic section along the geophysical track. There were three objectives:

1. Use geophysics to determine bottom and sub-bottom characteristics in the vicinity of unidentifiable persistent bottom reverberation areas.

2. Determine the conditions for reverberation with respect to bottom type and roughness.

3. Determine the extent and character of bottom-acoustic penetration.

3 General characteristics of the low frequency active sonar system

The acoustic source is carried in a large, towed fish designed and built as part of a joint programme between SACLANTCEN and NUWC (Naval Undersea Warfare Centre). Its weight in air is 4045 kg and its towed weight in water is 1136 kg. It is usually towed no deeper than 200 m up to a speed of 16 kn. To have sufficient acoustic power output and a narrow vertical beam width at low frequencies, a stack of five transducers per side operates at a resonant frequency of 600 Hz. A second set of transducers has a resonant frequency of 3000 Hz. and a vertical beam-width of 16° steerable between +45° and -45° from horizontal in 5° increments. The sysytem operates at frequencies from 200 Hz to 4000 Hz.

During the two experiments on the northern Malta Platform, the source was towed at speeds of 5 to 7 kn that the transducers were at a depth of 70 to 75 m. The maximum transmit acoustic power is 230 dB at transducer resonance. The bandwidth during the experiments was 200 Hz at the -3 dB points.

4

Characteristics of the Geophysical Survey equipment

Side-scan sonar and a high resolution reflection seismic profiler were used to examine the immediate seafloor sediments and the detailed vertical structure of the sediments and rocks beneath.

An EG&G Model 260-TH image correcting side scan sonar was used for this investigation. The towed fish, containing the transducers, was towed from a deck winch at the stern of NRV *Alliance*. The ship speed was adjusted to maintain the fish at 10 to 16 m above the seafloor. A height of 11–14 m was considered optimum and more than 80% of the survey was completed within this range. The plotted record width of each beam was 10 cm, the equivalent of 100 m on the bottom (calculated as 98.995 m for an average fish height of 14 m). A frequency of 100 kHz was used throughout the survey, resulting in a wavelength of approximately 1.5 cm. Minimum image resolution was 0.25 m. Thus even very small features on the bottom were capable of being resolved. It was not necessary to calculate the height of bottom features because the seafloor was found to be smooth, scarred sporadically by trawl marks.

The reflection seismic survey was carried out using a low-energy, high resolution system (EG&G model 265 UNIBOOM). A pulse of 300 J was used for the Uniboom generating an impulse of + 207 dB re 1μPa at 1 m source level in a bandwidth from 400-8,000 Hz. A towed 8 hydrophone receiver array had a sensitivity of 175 dB re 1 Volt re 1μPa in the range 1 Hz - 12 kHz. Resolution of the Uniboom is excellent because it produces a single sharp pulse. Real-time chart profiling at two scales was carried out for monitoring and analysis and the data was stored on analog videotape. This two-scale technique allowed imaging of different seismic perspectives of the upper sediment and proved to be useful for geological interpretation.

Horizontal scale bars (Figs 4–8) are based on average ship speed. Total ship speed variation was less than half a knot over the short line segments. Vertical scale bars are based on sound speed in sediment and rock of 2000 m/sec, which is a bulk estimate for the sediments and uppermost portion of the acoustic basement. Where marine sediment is thick, this velocity is an over-estimate and therefore the sediment is thicker than indicated in the figures. All references to sediment thickness are corrected using a recent sediment average velocity of 1580 m/s determined by measurements from sediment cores taken during a previous cruise [5].

5 Seafloor environmental characterization of the Malta Plateau

The seafloor in the northern Malta Plateau is comprised of two distinct bottom types or terranes having different geoacoustic properties. The easternmost is the Ragusa Terrane, which is a ridge of rough seafloor composed of irregular areas of exposed rock, often with a local, thin, recent, marine sediment veneer, rarely exceeding 1 m in thickness, which extends from the tip of SE Sicily through the Malta archipelago (Fig. 1). This ridge has been subject to, and is still undergoing weak tectonic uplift. It is also undergoing marine erosion, with a little deposition in sheltered shallows and off its flanks to the east and west. The seafloor characteristics within this terrane vary considerably depending on whether sediment patches are present and local roughness of the rockhead.

To the west of the Ragusa Ridge is the West Malta Plateau Terrane. This is an area of smooth seafloor, formed by an uppermost geological unit of continuous, recent marine sediment which varies from 3 m to 6 m in thickness, occasionally up to 13 m in areas where it fills eroded holes. Approaching southern Sicily, the marine sediment wedge thickens to a maximum of 25 m to 30 m. This unit is composed of soft, laminated muds and silts expressed on the reflection seismic records as a series of seafloor-parallel light and dark striping. Older sediments are composed of partially lithified sands, silts, muds, and limestones [6], [7] which are much harder and have a higher acoustic velocity.

The boundary between recent and older underlying sediment has been described as a local subareal unconformity to a water depth of about 145 m (the local maximum sea level fall). During the last glacial maxima, which ended only about 10,000 years ago, most of the Malta Plateau was land; the Malta archipelago was connected to Sicily by a land bridge. At this time, meandering streams cut a 1-3 m roughness into the top of a previous cycle of recently exposed older marine sediments, while they compacted and underwent subareal diagenesis. The subareal surface of this area was gently eroded by a series of small rivers flowing southward off Sicily. The courses of these buried rivers beneath the recent marine sediment were once continuous with the current Sicilian drainage pattern. The altered older sediments affected by subareal conditions no longer have their original marine sedimentary characteristics. No samples of this older sediment have been taken, but from the form of the eroded surface, there appears to have been sufficient strength in the material to support near vertical erosion surfaces such as the channel walls of streams.

6

Sub-seafloor LFAS environmental evaluation

Survey lines were laid out over a number of prominent features on the sonar response overlays prior to arrival in the area (Fig. 2). Line 1 was completed during the morning of 17 January, 1996, Lines 2 and 3 in the afternoon, using the Boomer (with two recorders recording at 10m and 20 m scales) and the EG&G side-scan. Line 2 was shortened from a longer planned line. Line 3 was carried out using the boomer and the EG&G side-scan going to the south and redone by going to the north using the Dowty side-scan (which was also operated at 100 kHz with approximately the same technical characteristics as the previously described EG&G side-scan), from which side-scan images were recorded in real time. Line 4 was investigated on the morning of 18 January.

The four lines investigated are described in the following sections.

Line1

Except for a small area at the northern end of line 1, the seafloor was almost completely featureless on the side-scan records. Water depths ranged between 85 and 38 m from south to north.

The southernmost E-W trail of sonar responses along line 1 is probably caused by reflection from the wall of a buried river channel about 5 - 6 m high that was imaged on 2 closely spaced lines (Fig. 2). On the western line segment, the channel shows the classic profile of a meandering stream, downcutting toward the north and forming a steep bank on the 'outside' of the stream bend (Fig. 4). The eastern intersection (Fig. 5) shows a more symmetrical channel, indicating a more straight course. Because both intersections showed a similar feature and there are no others that were imaged, it is probably the same channel. The lateral absence of the feature and the evidence for a stream bend in the western intersection, probably reflects an originally irregularly oriented channel. This flat shelf area would have had a meandering, rather than a straight river, with possibly many channels and entrenched meander bends. The lower part of the channel in both sections is filled with sediments which appear strongly laminated. These are probably marine re-worked sands and silts associated with the initial rise of sea level and the reworking of existing sands.

Other reverberation locations along the line to the north of the channel may be related to less conspicuous buried dune features or stepped erosional relics less than 2 m high in the lowermost sandy marine sediments. These could either be relic flood-stage deposits of the river or benches cut during sea level rise. These are less persistent than the buried channel and do not have such steep or high sides. This is consistent with the more scattered, patchy appearance of the sonar responses. At the northern end of line 1, there is an elevated lens which is probably a reef-like carbonate bioherm or bank on a small bathymetric high (Fig. 6).

Line 2

Two areas of observed anomalous reverberation were inspected. As along line 1, the seafloor was almost completely featureless on the side-scan records. Water depths ranged from 71 m to 35 m. The southernmost reverberation area was ill-defined, with weak, scattered returns from a broad area. These weak returns were probably generated by buried, moderately-sloped, dune-like features less than 3 m high at the base of the recent marine sediments.

The main reverberation area farther to the north, however, is related either to a nearly vertical, 40 m high, buried wave-cut cliff feature, having either a gravel bench or a carbonate patch-reef about two-thirds of the way up the cliff (Fig. 7) or to the rough buried hardground at the top of the cliff that is not as deeply buried by marine sediment. The gravel bench or carbonate patch-reef (Fig 7) reflects the level of a temporarily stable sea level position during the overall rise of sea level to its present position. The sediments below the reef (Fig. 7) are interbanded limy reef detritus and off-bank muds commonly found downslope from reefs. The base of the cliff marks an important sea level lowstand, and the reef an intermediate stable sea level height or pause in sea level rise. The seafloor above this buried feature gently slopes up towards the north, with soft parallel banded marine sediment filling sub-bottom roughness.

Line 3

Line 3 was a series of short lines across a zone which was characterized by a uniform, strong sonar reflection signal from many locations. The line was located near the eastern margin of the flat sedimented area, near an abrupt transition to the rocky platform of the Ragusa ridge, which extends SSE from the SE tip of Sicily (Fig. 1). Water depths ranged from 112 m to 89 m.

This sonar response zone was produced by reflections from a steep sided, rocky, cliff face and ridge having a buried cliff face which emerges from the floor of the basin to a height of 15 m high (Fig. 8). These features mark the eastern margin of the sedimentary basin underlying the western Malta Plateau. Eastward from the marginal ridge, the seafloor is again deeper. Therefore, looking from the LFAS source depth to the west, the ridge forms an acoustic shadow zone behind it to the east in which the rough rocky seafloor is only seen by reflections from submarine pinnacles. The low grazing angle of the LFAS source energy does not illuminate the rock platform as a whole, only the ridges and pinnacles, which creates reflections dependent on the geometry to the source/receiver.

Line 4

Line 4 was established in an attempt to identify an intermittent reflector and a strong, discrete reflector near the middle of the line recorded in the vicinity of a reported wreck (Fig. 2). Recorded water depths were 138 m to 125 m. A strong reflector thought to be caused by a large facet of the eastern rocky margin to the sedimentary basin was not in its anticipated position. The side-scan was used along the western part of the line, but was recovered for minor repairs; the eastern part of the line was

covered using the seismic profiler and the multibeam Swath mapper in both bathymetric and backscatter modes.

Reflection seismics along the line showed only a typical section of horizontally bedded marine sediment and the underlying older sediment of the West Malta Plateau basin; no evidence of a volcanic or up-faulted edifice was seen which would produce the observed anomalous sonar response. The marine sediment surface layer is no thicker than about 8 m. The erosional subareal surface has a low roughness, with a few buried channels up to 1.5 m deep, none of which was near the anomalous sonar response. The deeper horizontally stratified sediments continue for the whole section except at the SE end where they pinch out against an abrupt cliff feature, which is coincident with LFAS sonar response zone at the eastern margin of the sedimentary basin.

The seafloor itself is almost flat and featureless to the west of the cliff marking the western margin of the Ragusa Ridge. No bathymetric feature coincident with the anomalous sonar responses was detected using the Swath mapper, but a hardware fault was found in the instrument following the cruise which may have precluded the detection of a bathymetric high.

When the swath data was processed to yield a backscatter map, however, there was evidence of an object on the seafloor at about the position of the anomalous LFAS responses. A backscatter image of the swath was formed from the signal received from the seafloor as greyscale pixels and false coloured for the onboard Atlas display. Because the backscatter image is formed by locating each pixel along the swath for each pulse group, and no averaging or other processing is done with groups of acoustic returns, the backscatter image was not as disturbed by the hardware fault as the computed bathymetric output; it can be regarded as a reliable backscatter strength map of the ensonified area.

The swath itself is 550 m wide at the location of the linear object. The object itself appears to be about 125 m long and lying about NS (Fig. 9). The object is probably real, rather than being an anomalous beam artifact because it does not lie orthogonal to the ship's course. It thus cannot be an artifact produced by a short-term beam perturbation. Pixel resolution in the 125 m to 138 m water depth along the line (129 m at the object position) is about 20 m (along ship's course) x 15 m (orthogonal to ship's course). Processing rendered the coordinate system for pixel axes related to the ship's orientation (e.g., x-axis along swath) to a coordinate system related to the Cartesian grid of the visualization software and the monitor (y axis north). The object appears to be about 2 pixels wide (30 m to 40 m wide) at its widest, tapering at the northern end.

The object is probably a wreck. Nothing is known of the reported wreck nearby [8] apart from its position. Both the width and length appear to be longer than an intact ship. If the backscatter object is the wreck recorded nearby, (Fig. 10), then it is probably in more than one piece on the seafloor.

7

Conclusions and recommendations

Every LFAS response which had previously been regarded as anomalous and investigated (Fig. 2, lines 2 and 3) was found to be related to a buried reflector within the seafloor (Fig. 11). The seafloor above the responses consisted of a relatively thin layer of recent sediment having a generally smooth and flat surface, showing only scattered trawl marks which is acoustically banded on the reflection seismics. No indication of gravel banks, sand bars or other high backscatter patches was present.

Along lines 3 and 4 (Fig. 2), the major LFAS responses were probably caused by submarine cliff faces. The acoustic response from these reflecting cliff faces differed to the buried reflectors by being stronger and better defined. The marine sediment masking the positions of the buried reflectors appears to cause some signal attenuation. Ideally, attenuation should be calibrated for the frequencies of interest as a function of sediment type and thickness as part of an LFAS ASW environmental analysis.

A buried reflector is also a probable cause for the isolated anomaly 'A' (Fig. 11), for which no surface or sub-surface cause could be identified.

In one case (Fig. 2, line 4; Figs. 9, 10), the investigated response probably was related to a wreck on the seafloor.

The location of a number of sonar responses at positions differing from their actual position relative to the LFAS source and receiver is the result of propagation of the acoustic energy through the higher acoustic velocity (compared with seawater) marine sediment. Where propagation through marine sediments is suspected, some account should be given to a higher acoustic velocity for at least part of the 8-12 km range at which most of these buried reflectors would be imaged.

The results of this environmental evaluation indicate that attention must be given to predicting the likelihood of buried features contributing to the reverberation and response pattern of continental shelf areas. The methodology for the operational use of LFAS should include as complete geological and geophysical analysis as is possible. This should include identifying the existence and location of buried reflectors and their likely orientation, or at least a prediction of their presence based on geological interpretation of the area of interest.

Bathymetric information or side-scan sonar information from the northern Malta Plateau area, or point information such as sediment sampling no matter how detailed, would give a minimal indication of buried, potential reflectors. A complete geoenvironmental reverberation analysis for continental shelves suitable for producing predictive charts for LFAS should contain:

a. Geophysical properties for determining bottom and sub-bottom character based on high resolution shallow reflection seismics for locating possible buried reflectors.

b. Identification of potential environmental background 'noise' for LFAS including databases and an understanding of geological history to optimize the likelihood of identifying relevant features.

References

[1] Max, M.D. Acoustical transmission anomalies in the Southwest Approaches to the British Isles: Geoacoustic terranes and the characterization of bottom and sub-bottom interaction in shallow water. NRL 9165, Washington D.C., Naval Research Laboratory 1989

[2] Bender, M., Sowers, T., Dickson, M.-L., Orchardo, J., Grootes, P. Mayewski, P.A. & Meese, D.A. Climate correlations between Greenland and Antarctica during the past 100,000 years. *Nature* **372**, 1994:663-666.

[3] Max, M.D., Michelozzi, M. Tonarelli, B. A Weichselian low stand beach terrace at -131 m in the southern Adventure Bank, off SW Sicily. *Geological Society of London Special Publication* (in press).

[4] Shennan, I. Holocene sea-level changes and crustal movements in the North Sea region: and experiment with regional eustasy. In: Scott, D.B., Pirazzoli, P.A. & Honig, C.A. (eds). Late Quaternary Sea-Level Correlation and Application. Dordrecht, Kluwer, 1989:pp.1-25.

[5] Tonarelli, B., Turgutcan, F., Max, M.D., Muzi, E. & Akal, T. Sediment analyses from the Sicilian-Tunisian Platform. A summary of SACLANTCEN sites to December, 1992. Area C: Central Malta Plateau, SACLANTCEN M-111. La Spezia, Italy. NATO SACLANT Undersea Research Centre. 1992

[6] Max, M.D. & Colantoni, P. (eds). The Geological Development of the Sicilian-Tunisian Platform. *UNESCO Technical Report in Marine Sciences*, **58**, 1993.

[7] Max, M.D. & Colantoni, P. 1993. Geomorphological position and geology of the Sicilian-Tunisian Platform. *UNESCO Technical Report in Marine Sciences*, **58**, 1993: 1–2.

[8]U.S. Defense Mapping Agency. Non-Submarine Sonar Contact List. 1994

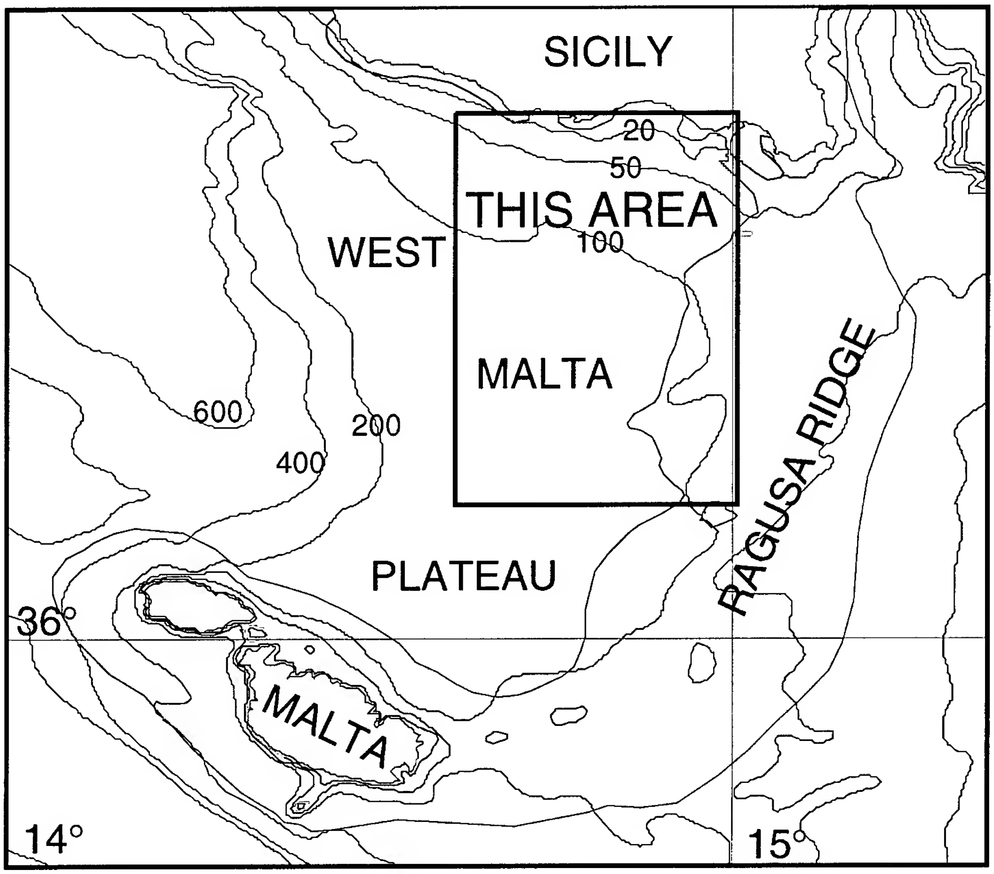

Figure 1 *Map of the LFAS environmental survey area. Note the Ragusa Ridge passing from SE Sicily through the Malta archipelago.*

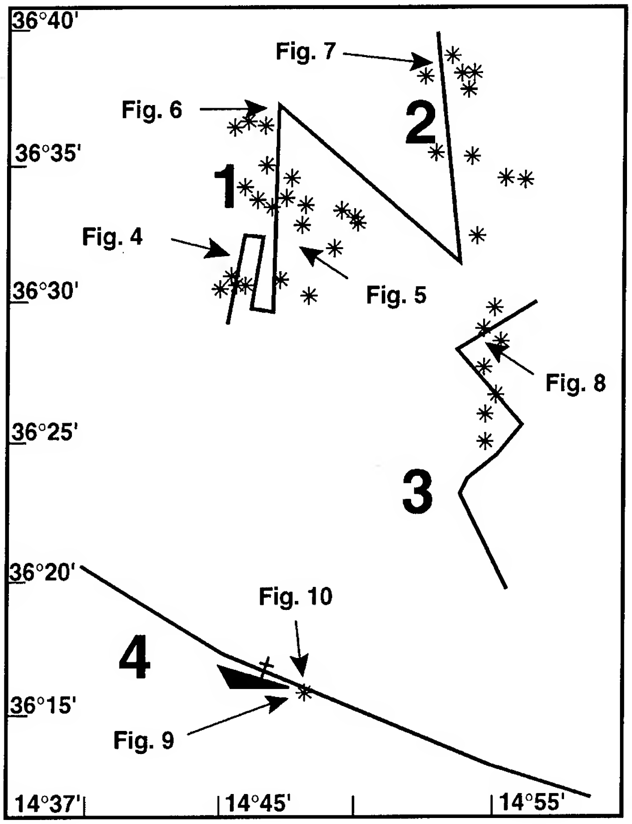

Figure 2 *Map showing the 4 lines investigated. Red asterisks show persistent individual reflectors including reported wreck the position of which is shown (Fig numbers indicate areas where details are presented in later illustrations).*

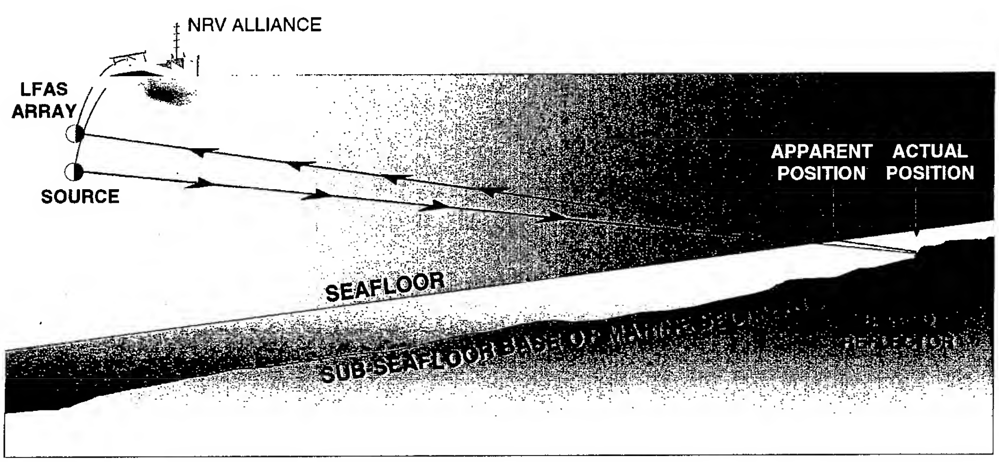

Figure 3 *Geometry of the LFAS system, seafloor, and potential buried reflectors. Note that the apparent position of the reflector may be closer to the source/array because of the higher acoustic velocity of the marine sediment, over part of the propagation path.*

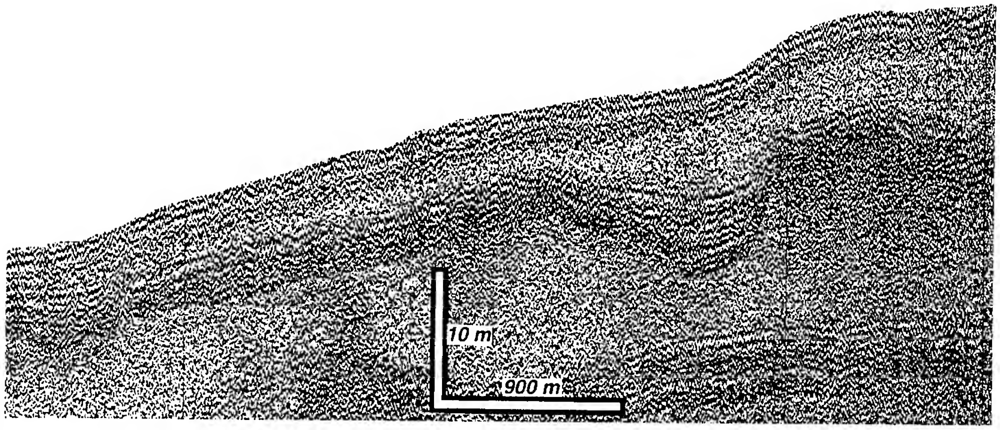

Figure 4 *Buried asymmetrical river channel. Note filling of lower part of channel with re-worked sands.*

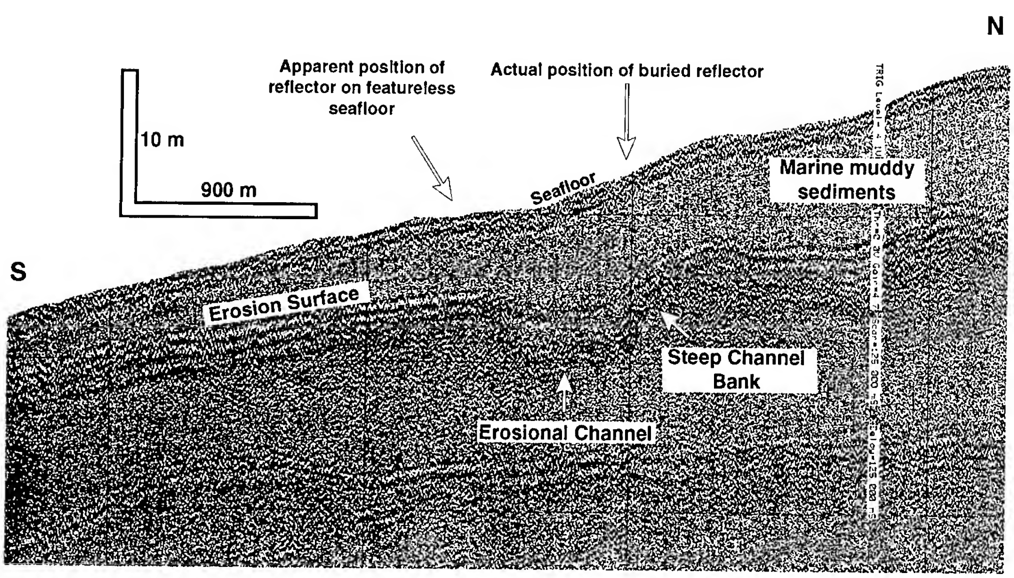

Figure 5 *Buried symmetrical river channel. Note filling of lower part of channel with re-worked sands.*

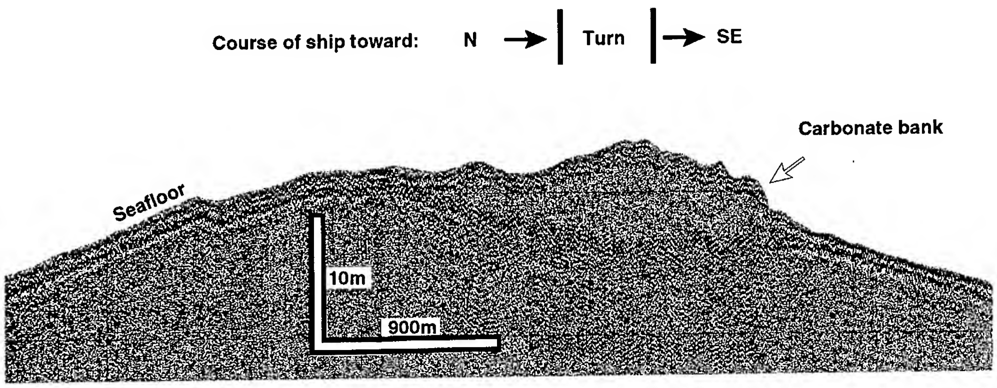

Figure 6 *Carbonate bioherm near crest of a small submarine rise. Hill-like effect is the result of ship moving to the north up the submarine slope and then turning to the SE and moving down-slope to the southern end of line 2 (Fig. 2).*

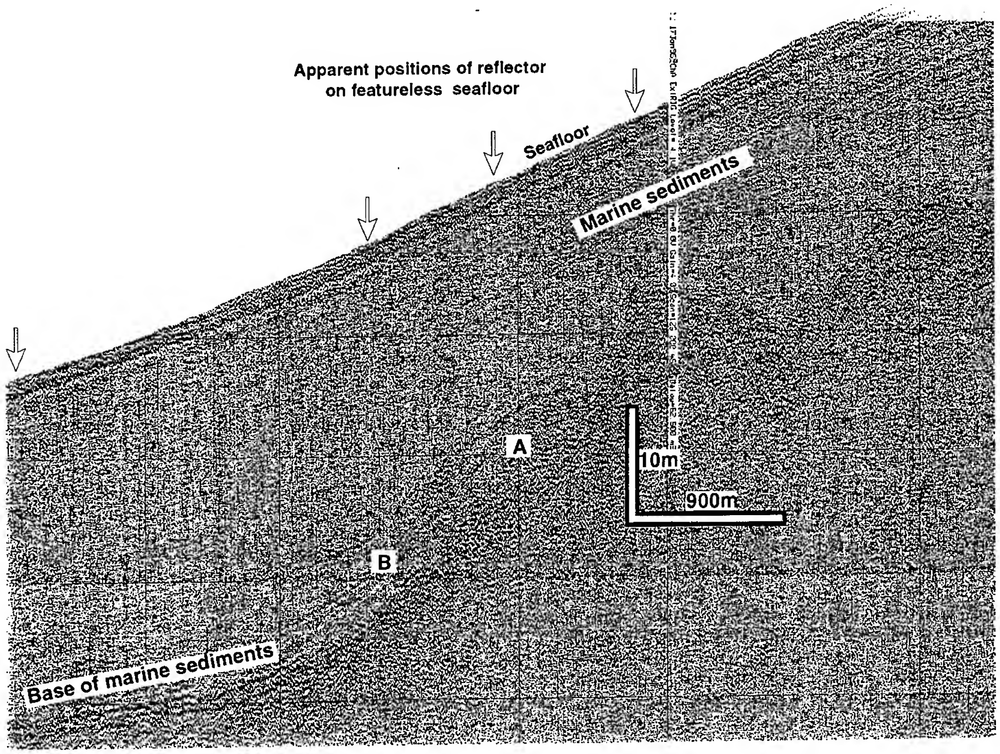

Figure 7 *Buried cliff and reef feature with rough ground rockhead above cliff. Scattered reflectors here probably indicate many facets over a broad area of the cliff face and above it. A indicates gravel bench, B sediments.*

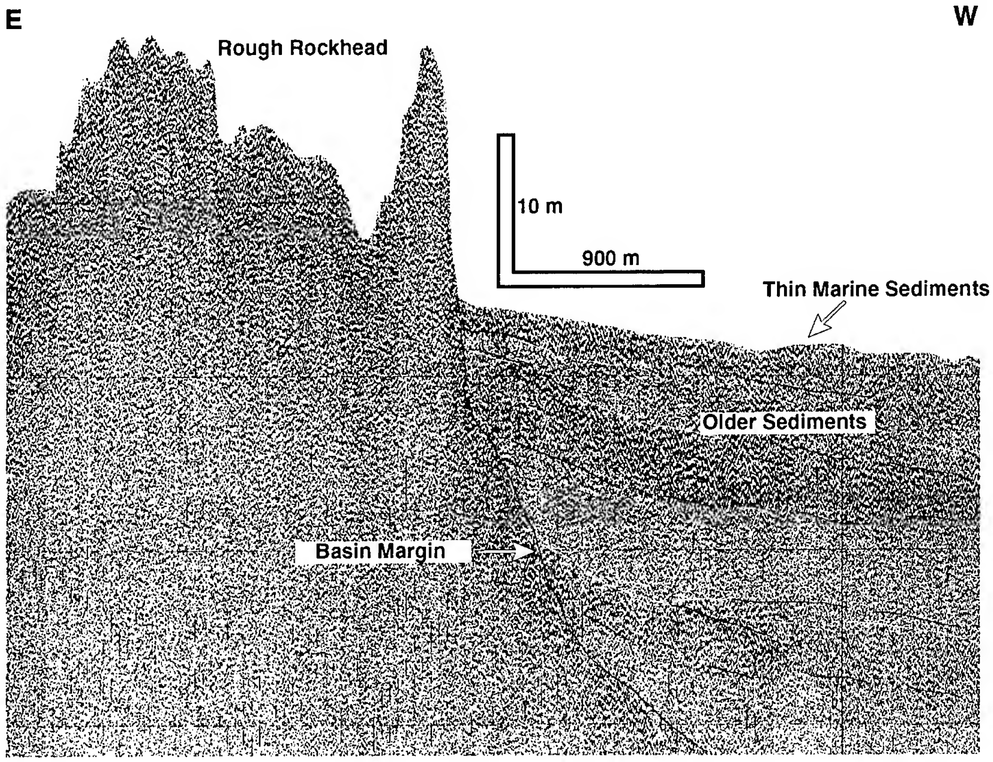

Figure 8 *Cliff face at the margin of the Ragusa Ridge coincident with sonar responses.*

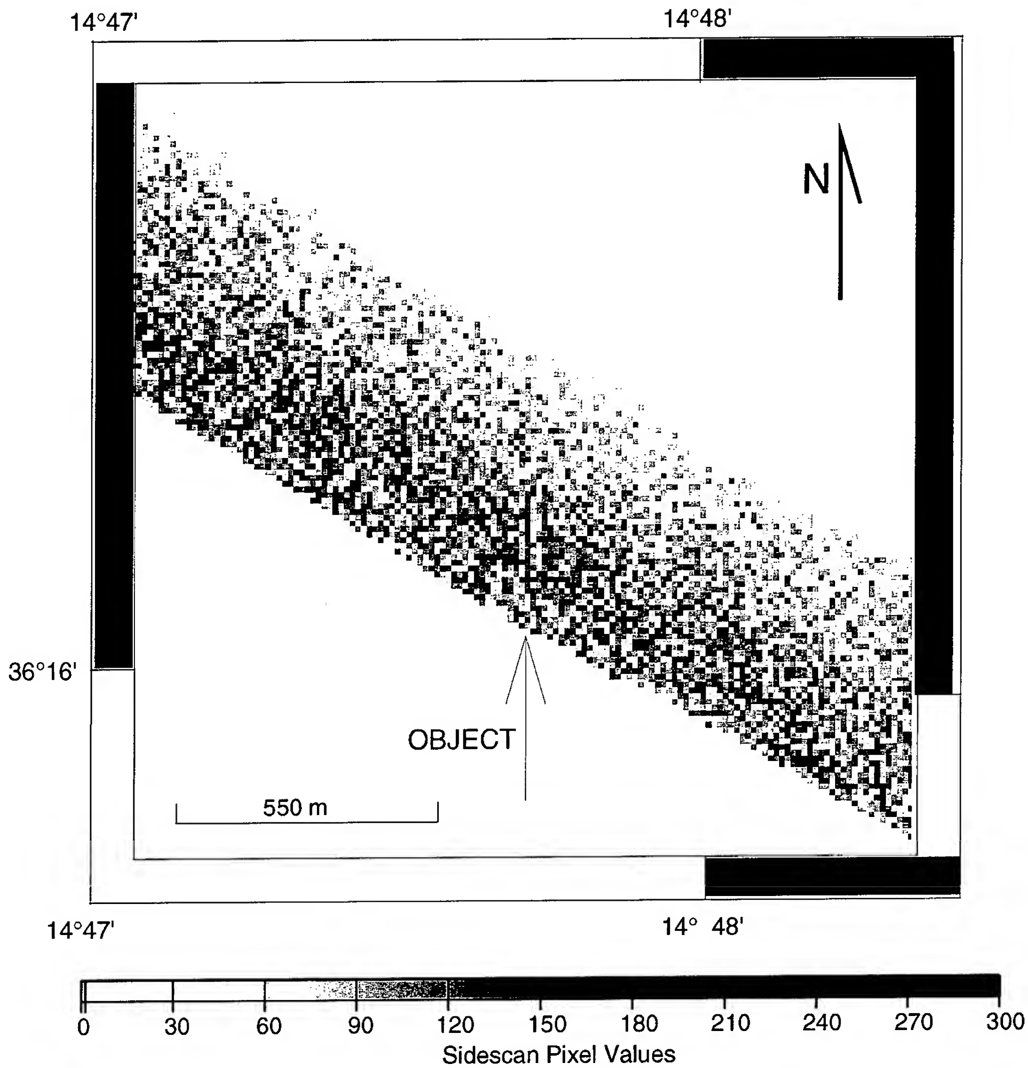

Figure 9 *Greyscale backscatter chart of part of the swath for line 4. This backscatter 'object' interpretation is highly subjective but occurs in approximately the correct position to be real.*

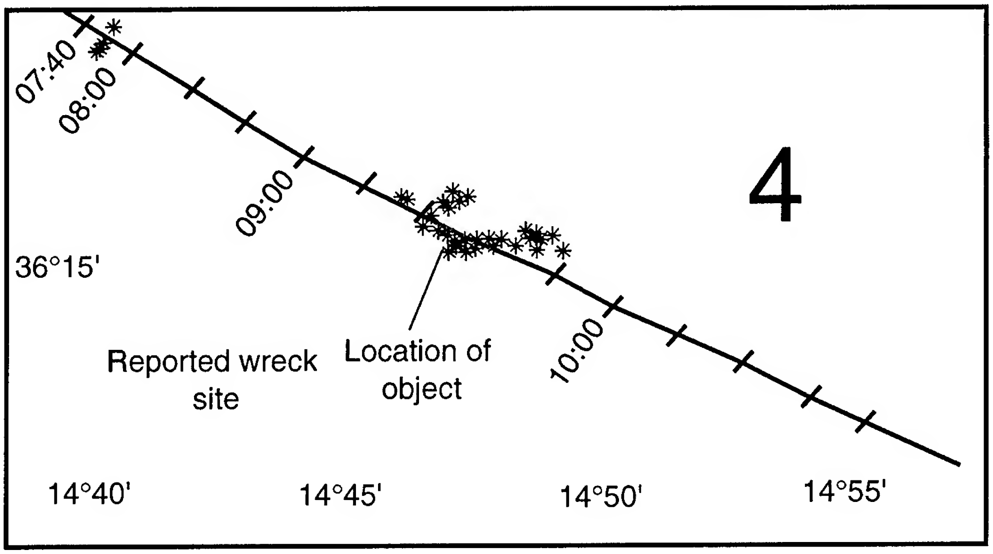

Figure 10 *Detail of line 4 showing the positions of the backscatter 'object', the reported wreck, and the mapped sonar response positions.*

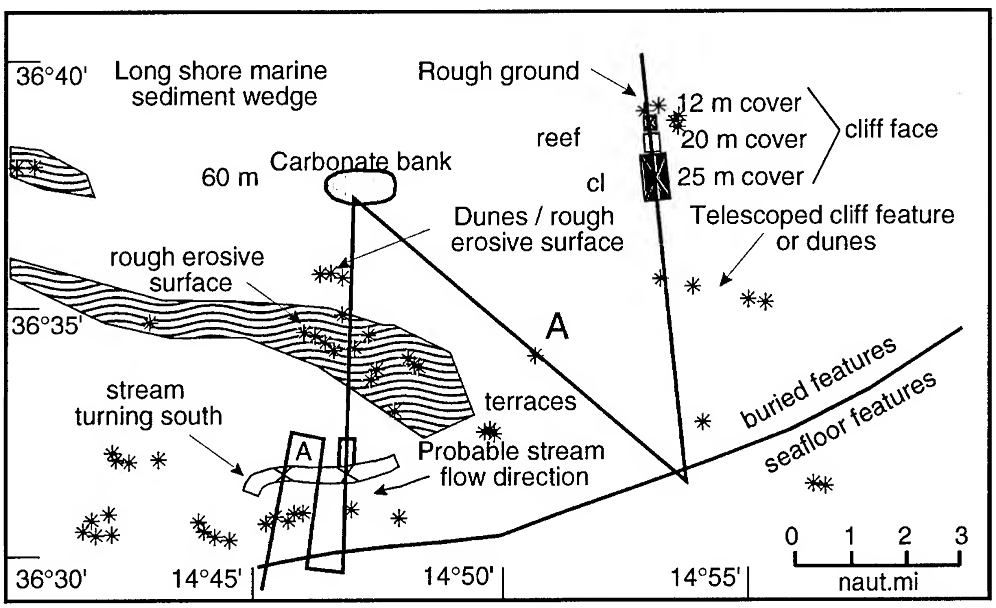

Figure 11 *Annotated sonar response diagram for the northern part of the west Malta Plateau. Red and blue indicate areas of persistent responses. Black lines are investigation lines. 'A' is a solitary response for which no buried reflector was found.*

Document Data Sheet

NATO UNCLASSIFIED

Security Classification		Project No.
NATO UNCLASSIFIED		042-3
Document Serial No.	**Date of Issue**	**Total Pages**
SM-306	June 1996	25 pp.

Author(s)

M. D. Max, N. Portunato & G. Murdoch

Title

Sub-seafloor buried reflectors imaged by Low Frequency Active Sonar

Abstract

Low Frequency Active Sonar (LFAS) utilizes low-frequency acoustic emissions to detect submarines. Where strong reflections occur on the seabottom which produce environmental scatter (reverberation), response from the submarine target may be masked or false contacts may be reported. Constructing predictive maps of anticipated sonar response zones in order to identify the background clutter is thus one of the main goals in the preparation of environmental data sets for areas in which LFAS may be employed operationally.

It has been demonstrated that reflectors buried in the seafloor can cause substantial reflections that will be mapped geographically incorrectly where the incident acoustic ray-paths pass back from the buried reflector toward the receiving array through the seafloor. Thus, it is necessary to characterize fully both the seafloor *and* the sub-seafloor acoustic response of shallow water areas in which LFAS ASW operations may be carried out

Keywords

LFAS – low frequency active sonar – false contacts – bottom properties

Issuing Organization

North Atlantic Treaty Organization
SACLANT Undersea Research Centre
Viale San Bartolomeo 400, 19138 La Spezia, Italy

[From N. America: SACLANTCEN CMR-426 (New York) APO AE 09613]

Tel: +39 (0)187 540 111
Fax:+39 (0)187 524 600

E-mail: library@saclantc.nato.int

NATO UNCLASSIFIED